

Pongsatorn Kerdoum; Suttichai Premrudeepreechacharn

Article

Analysis of PV penetration level on low voltage system in Chiang Mai Thailand

Energy Reports

Provided in Cooperation with:

Elsevier

Suggested Citation: Pongsatorn Kerdoum; Suttichai Premrudeepreechacharn (2020) : Analysis of PV penetration level on low voltage system in Chiang Mai Thailand, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 6, Iss. 2, pp. 754-760, <https://doi.org/10.1016/j.egy.2019.11.151>

This Version is available at:

<https://hdl.handle.net/10419/243964>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

The 6th International Conference on Power and Energy Systems Engineering (CPESE 2019),
September 20–23, 2019, Okinawa, Japan

Analysis of PV penetration level on low voltage system in Chiang Mai Thailand

Pongsatorn Kerdoum^{a,b,c}, Suttichai Premrudeepreechacharn^{a,*}

^a Department of Electrical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, Thailand

^b Graduate School, Chiang Mai University, Chiang Mai, Thailand

^c Provincial Electricity Authority, Bangkok, Thailand

Received 19 October 2019; accepted 23 November 2019

Abstract

This paper presents the various levels of photovoltaic (PV) penetration which strongly affect the voltage quality in low voltage systems. The rural area of the Provincial Electricity Authority (PEA) in Chiang Mai is selected as a case study. DIGSILENT PowerFactory program is used to simulate the PV solar rooftop 1-phase on the selected area. This paper analyzes the impact of the PV solar rooftop in various locations and PV penetration levels with the PEA voltage standard. Next, the technical solution by transformer relocation is proposed. The results are compared with the worst case and analyzed the possibility of the solution. The results from the worst case show that only 30% of PV penetration is acceptable in PEA voltage standard and the solution can mitigate the PV penetration level.

© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of the 6th International Conference on Power and Energy Systems Engineering (CPESE 2019).

Keywords: PV penetration; Low voltage system; Single phase; Line impedance; Solar rooftop

1. Introduction

The Thailand renewable energy policy called “Alternative Energy Development Plan” AEDP [1] has supported and promoted Thai people to install the renewable energy such as photovoltaic (PV), as well as wind energy. In 2036, this plan aims to have the PV powerplant around 6000 MW and the PV solar rooftop from the household area about 300 MW. The Provincial Electricity Authority (PEA) is a utility which provides electricity in Thailand, where responsible areas are almost all over the country. Moreover, PEA is a department to configure the grid code rules used to define the parameter of the grid-connected to the PV solar rooftop. From the above conditions, many Thai people are interested in installing the PV solar rooftop. However, high PV penetration caused by installing the PV solar rooftop rapidly will make a great impact on the distribution system. Therefore, it is important to review and update the grid code rules for supporting high PV penetration.

* Corresponding author.

E-mail addresses: pongsatorn.kar@pea.co.th (P. Kerdoum), suttic@eng.cmu.ac.th (S. Premrudeepreechacharn).

<https://doi.org/10.1016/j.egy.2019.11.151>

2352-4847/© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of the 6th International Conference on Power and Energy Systems Engineering (CPESE 2019).

From the literature review, Eftekharijad et al. [2] have focused on a large distribution system. The results show that high PV penetration can impact on a voltage deviation; 20% of PV penetration is the beginning of the problem. However, the violation of the problem depends on the location of the PV penetration. Papaioannou et al. [3] has studied the effect of the voltage and the harmonic caused by the PV penetration. The 6-node simulations in low voltage show that around 18% of the PV penetration caused the overvoltage to the low voltage system, especially at the nodes which are distant from the transformer. Harmonic issues were also investigated for various topologies and penetration levels. However, no violation of harmonic limits was detected. Punyachai et al. [4] analyzed the intermittent of light intensity throughout the day for 2 objectives. First was to find out when the overvoltage occurred. The second was to examine the distance between the solar rooftop installed. The results show that increasing distance between the solar rooftop increases the chance to cause the overvoltage problem. Aziz and Ketjoy [5] have shown that the power limitation of the PV solar rooftop was analyzed by defining various areas, the light intensity, and the load profile. The results by Hashemi and Ostergaard [6] revealed that the areas with low load profile encountered the overvoltage problem. Therefore, it is necessary to define the PV solar rooftop correctly for solving the problem.

This research aims to study the impact of the voltage profile in various location of PV penetration level. A rural area of Chiang Mai Thailand is selected as a case study. This research uses DIgSILENT PowerFactory to simulate 1 phase of the PV penetration for problem analysis. In addition, it also presents a solution method by moving the installation of the transformer.

2. Theoretical analysis of grid-connected PV

The 2-bus system in Fig. 1 is used to show the equation of the voltage at the beginning point and end point as shown in (1)–(3) where V_{PCC} is the voltage at point of connection, V_G is the voltage at transformer, $R_L + jX_L$ is the line impedance, I is the line current, S is the apparent power from grid to Bus, S_{PV} is the apparent power from the PV system, and S_{LD} is the load consumption. If the PV power generation is more than the consumption load at the PCC point, the grid will absorb the power. If the PV power generation is less than the consumption load at the PCC point, the grid will supply the power to the load.

$$S = VI^* \tag{1}$$

$$\vec{I} = \frac{P - jQ}{\vec{V}_{PCC}^*} \tag{2}$$

$$\vec{V}_G = \vec{V}_{PCC} + \vec{I}(R_L + jX_L) \tag{3}$$

$$\vec{V}_{PCC} = \vec{V}_G - \left[\frac{PR_L + QX_L}{\vec{V}_{PCC}^*} - j \frac{R_LQ - PX_L}{\vec{V}_{PCC}^*} \right] \tag{4}$$

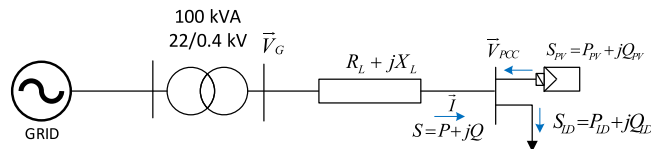


Fig. 1. 2-bus system used to explain the voltage equation.

Equation in (4) refers to power flow at PCC point. After comparing between active and reactive power, it can be presented as (5)

$$\vec{V}_{PCC} = \vec{V}_G - \left[\frac{(P_{LD} - P_{PV})R_L + (Q_{LD} - Q_{PV})X_L}{\vec{V}_{PCC}^*} \right] \tag{5}$$

Hashemi and Ostergaard [6] have proposed the voltage problem which caused by PV solar rooftop relies on important factors below and these factors are the key to find a solution to the voltage problem.

- System load consumption
- PV power generation
- Line Impedance: location of the PV installation, type of line.

2.1. Interconnection Code of PEA by Provincial Electricity Authority [7]

- Voltage standard: The PEA voltage standard range is between 200 to 240 V. or 0.9 to 1.1 pu. This range is used to verify the voltage result.
- Power capacity: The power is purchased from power producers at voltage level 380/220 V distribution system. A power producer can connect to a single-phase distribution system, only if the system can supply capacity no more than 5 kW. In case that the power producer wishes to connect the single-phase distributions to a power network system, capacity supplied to each phase must be stable; that is, the different values of voltage between each phase must not exceed 5 kW. The total power capacity from each connection requester's generator connected to the same transformer must not exceed 15% of the distribution transformer load (kVA). The purposes of this study are to review the requirements and to increase the amount of power needed to connect the distribution system.

3. Research methodology

3.1. The simulation case studies

The simulation case studies choose a rural area of the Chiang Mai which uses the 22 kV/400 V distribution system of PEA by Suksornchai et al. [8]. This system consists of two feeders, 100 kVA transformer, and 67 rural loads (1 phase, 3 phase) as shown in Fig. 2. The case studies are imported and simulated in DIgSILENT PowerFactory program.



Fig. 2. Low voltage distribution system of the Provincial Electricity Authority in Chiang Mai which installed transformer 100 kVA.

Fig. 3 Shows the low voltage distribution system simulation in DIgSILENT PowerFactory program which uses in this paper. This system is used to analyze the size and location of installing the PV which has effects on the voltage profile. The longest distance of load is 540 m used for measuring the voltage and distance between houses around 20 to 100 m, while the transformer is installed at the middle point of the system. Distance from left is 540 m and distance from right is 330 m.

3.2. Load profile and the PV power generation

This study employs the load profile from [9] to represent the load in a rural area of Chiang Mai. This load profile is selected in February due to the minimum demand in the year. Fig. 4. illustrates the daily load curve at 0.85 powerfactor and the total PV power generation used in case studies.

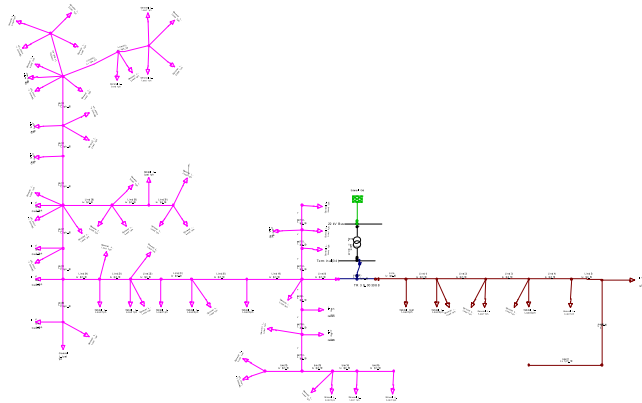


Fig. 3. The low voltage diagram of PEA distribution system in Chiang Mai.

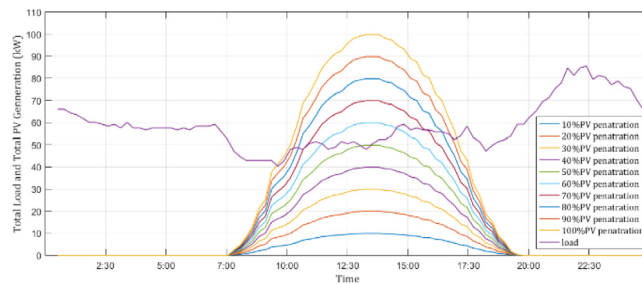


Fig. 4. The daily load curve and the total PV power generation.

3.3. The parameters of the system

Where Nominal voltage (L-L) is 380 V, PEA Voltage Standard Range is between 0.9–1.1 pu., Type of Line is 50 sq.mm. Aluminum, Resistance is 0.571 (Ω/km), Reactance is 0.271 (Ω/km), Transformer ratio is 22,000/400 V, Secondary Voltage is 400/230 V, Rating 100 kVA, Type Dyn 11, Frequency 50 Hz, %Z is 4%, No-Load Loss is 250 W., Load Loss at 75 °C is 1,550 W., Number of Meter 3 Phase is 12 house, and Number of Meter 1 Phase is 55 house

4. Simulation and result

4.1. Case studies

In this research, case studies are used to analyze the percentage of acceptable PV power generation. Various sizes and locations for installing the PV are also considered. Three case studies consist of (1) installing the same PV location at the transformer, (2) installing the PV distribution throughout the system, (3) installing the PV at the farthest load.

- Case study 1: the PV is installed at the same location of the transformer and near 10 houses with solar rooftop by connecting four houses on phase A, three houses on phase B, and three houses on phase C. The PV penetration increases from 10% to 100% by using 10% per step.
- Case study 2: the PV is randomly installed throughout the system on 10 houses with solar rooftop. The PV has connected four houses on phase A, three houses on phase B, and three houses on phase C. This case is almost the same as the real situation in the PEA system.
- Case study 3: the PV is installed around the end of the line location on 10 houses with solar rooftop, while other conditions are similar to case study 1.

4.2. Results

The PEA voltage standard level is 0.9–1.1 pu. The all-day voltage profile from three case studies is shown in Fig. 5.(a), (b), (c) respectively. In Fig. 5(a), (b), (c), the voltage increases when the PV starts to operate in the morning and decreases in the evening. In case 1, the voltage with all PV penetration level is still acceptable in the PEA voltage standard. In case 2, phase A voltage at 70% of the PV penetration level starts to violate the PEA voltage standard. In case 3, only less than 40% of the PV penetration level is acceptable in the standard. If the PV penetration level is more than 40%, the voltage of the system will exceed the standard which negatively affects the household. The results from three case studies show that the location of the PV penetration level directly affects the voltage profile system.

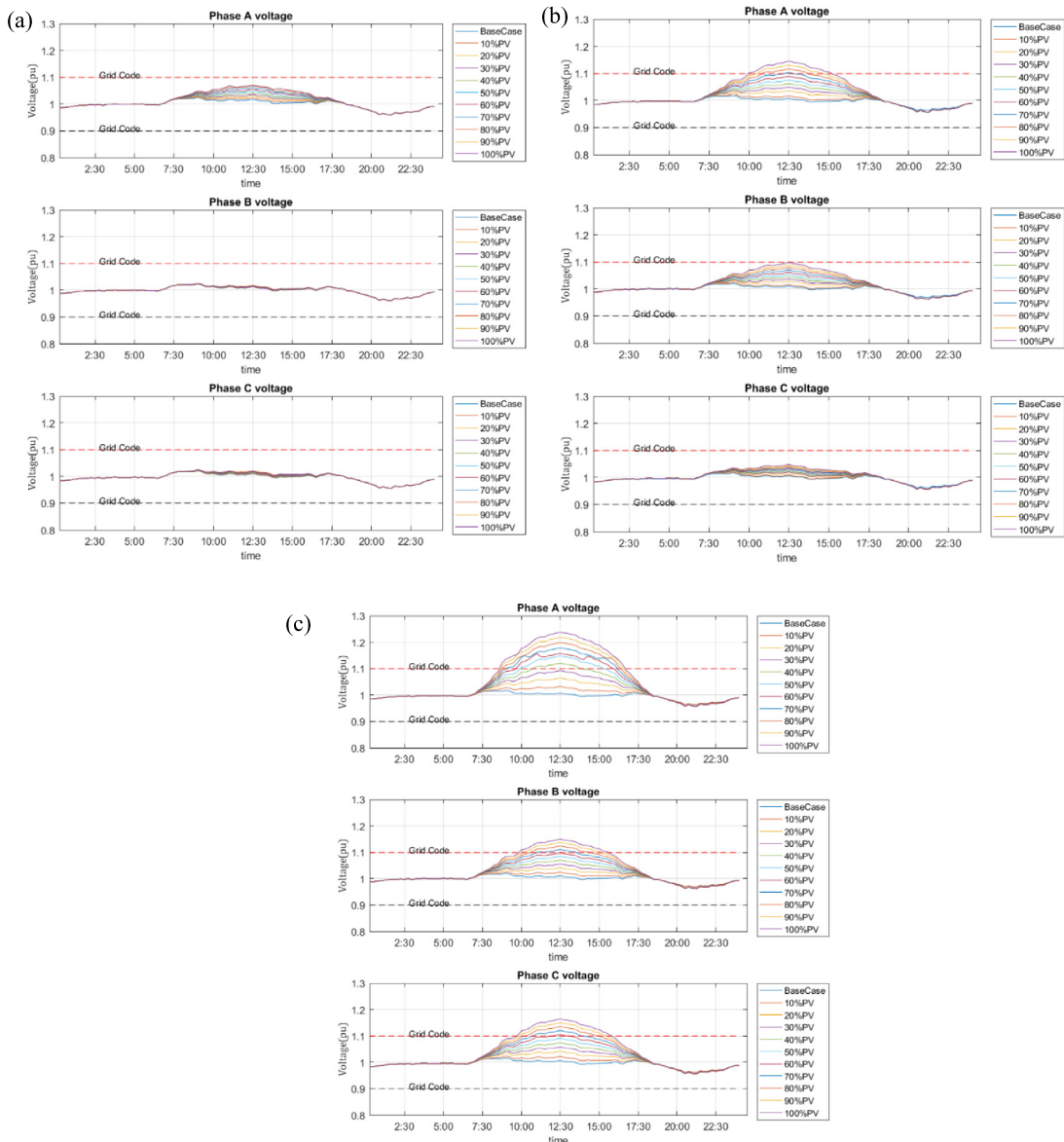


Fig. 5. (a) The all-day voltage profile from case study 1; (b) The all-day voltage profile from case study 2. (c) The all-day voltage profile from case study 3.

The all-day voltage results from Fig. 5(a), (b), (c) are clearly different due to the location of the PV installation and impedance line differences. Various locations show the actual situation of the PEA rural area in Chiang Mai.

Fig. 6 shows the ratio of the PV penetration level and the voltage level of the system at peak time. It can be concluded that 30%–40% of the PV penetration level can cause the overvoltage to the system.

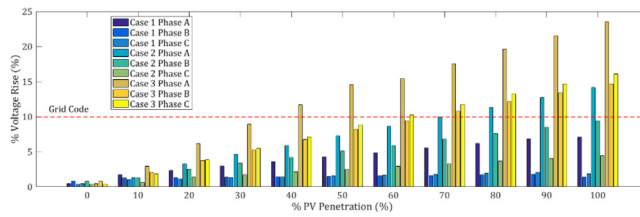


Fig. 6. The comparison of the PV penetration level increased in 3 case studies.

4.3. Mitigation strategy

The results show that no voltage violation in case 1 because the line impedance between PV location and transformer is low. Therefore, it can be noticed that low line impedance between PV location and transformer can control the voltage level from PV penetration.

This paper shows a mitigation strategy to reduce the line impedance by moving the transformer location near to the PV location. This strategy is simulated in low volt system case studies in which the system has different in length and load. The case studies relocate the transformer in Fig. 7 to the left 200 m as shown in results of case 2 and 3. The voltage profile after relocating the transformer is acceptable in the PEA voltage standard.

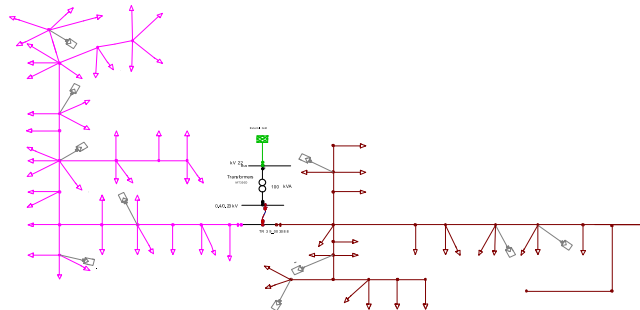


Fig. 7. The new location of the transformer after relocating from case 2.

Fig. 8 shows the comparison of voltage before–after the transformer relocation. The results from improvement with case 2 show that the capacity of installed PV increases from 70% to 80%. The voltage at PV penetration

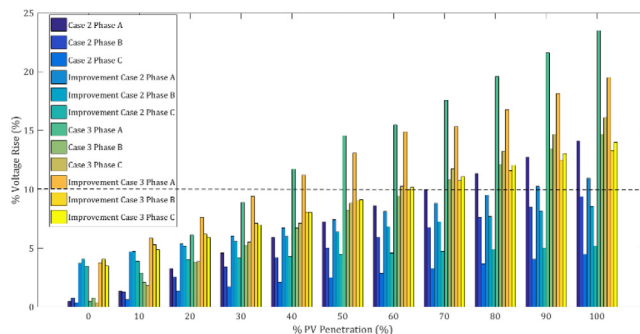


Fig. 8. The comparison of voltage results between case 2, case 3 and the transformer relocation.

level 10%–50% is increased by the transformer relocation. However, the voltage level is still acceptable in the PEA voltage standard. Next, the percentage of the voltage rise at PV penetration level 60%–100% is decreased due to the decreasing of line impedance from the transformer relocation. In case 3, the transformer relocation starts to decrease the percentage of the voltage rise at 40% PV penetration level.

5. Conclusion

In this paper, various levels of photovoltaic are analyzed with the voltage levels of the system. Different locations of the PV solar rooftop are selected as case studies. The results show that installing the PV solar rooftop around the end of the line will have lower PV capacity than other locations and the location near the transformer has more capacity of the PV penetration level than others. This is because the line impedance varies with the voltage level. The relocated transformer helps mitigate the voltage problem and increase the capacity of installing the PV solar rooftop in some case studies

Acknowledgment

The authors would like to appreciate the financial support from the Provincial Electricity Authority, Department of Electrical Engineering, Faculty of Engineering, and Graduate School, Chiang Mai University, Thailand.

References

- [1] Department of Renewable Energy Development and Energy Efficiency. Alternative energy development plan:2015 [online]. 2015, Available:<http://www.eppo.go.th/images/POLICY/ENG/AEDP2015ENG.pdf>.
- [2] Eftekharnjad S, Vittal V, Heydt TG, Keel B, Loehr J. Impact of increased penetration of photovoltaic generation on power systems. *IEEE Trans Power Syst* 2013;28(2):893–901.
- [3] Papaioannou Ioulia T, Alexiadis Minas C, Demoulias Charis S, Labridis Dimitridis P, Dokopoulos Petros S. Modeling and field measurements of photovoltaic units connected to LV grid. study of penetration scenarios. *IEEE Trans Power Deliv* 2011;26(2):979–87.
- [4] Punyachai R, Ongsakul W, Schmidt W. Impact of high solar rooftop pv penetration on voltage profiles in distribution systems. In: 2014 international conference and utility exhibition (ICUE). 2014, p. 1–7.
- [5] Aziz T, Ketjoy N. PV penetration limits in low voltage networks and voltage variations. *IEEE Access* 2017;5(2017):16784–92.
- [6] Hashemi S, Ostergaard J. Methods and strategies for overvoltage prevention in low voltage distribution systems with PV. *IET Renew Power Gener* 2017;11(2):205–14.
- [7] Provincial Electricity Authority. Provincial Electricity Authority's Regulation on the Power Network System Interconnection Code B.E.2559, Bangkok, 2016.
- [8] Suksornchai T, PaySirivran, Chumchawarit S. Modeling and analysis of PV solar rooftop install in low-voltage distribution system of PEA pea conference 2015. 2015, p. 56–63.
- [9] Provincial Electricity Authority. Load research of PEA. 2018, <http://peaoc.pea.co.th/loadprofile/> (Access 20 Nov. 2018).